Analysis of Iron Enhanced Sand Filter Monitoring Reports and Data

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This is a summary of the computations made to determine a IESF lifetime guidance for the Minnesota Stormwater Manual. Data from three IESF installations were collected and used for this guideline. There were other monitoring data sets that could not be used due to design alterations, and other data sets that were incomplete or were not made available.

IESF #1: Minnehaha Creek Watershed District Dutch Lake IESF pond-perimeter trench

Installed 2012: L = 140' + 70' = 210 ft W = 20 ft Surface area = 4200 ft^2

2013 Monitoring Report: Volume Flow estimate = 64 M gal / 7.48 gal/ft^3 = 8.6 X 10^6 ft^3
Length of flow through filter = 8.6 X 10^6 ft^3 / 4200 ft^2 = **2,050 ft = 626 m**
Performance at removing phosphate: 5/16/13 30.6% removal
5/29/13 43.3%
6/28/13 10.0%
7/29/13 26.1%

2014 Monitoring Report: Volume flow estimate = 97.8 M gal = 13 M ft^3
Length of flow through filter = 13 X 10^6 / 4200 = **3,095 ft = 943 m**
Total Length through filter = 943m + 626 m = **1,569 m (5,148 ft)**
Performance at removing phosphate: 5/22/14 30.4% removal
7/23/14 71.9%

2015 Monitoring Report: Volume Flow estimate = 95.6 M gal / 7.48 gal/ft^3 = 12.8 X 10^6 ft^3
Length of flow through filter = 12.8 X 10^6 / 4200 = **3,048 ft = 929 m**
Total Length through filter = 1,569 m + 929 m = **2,498 m (8,196 ft)**
Performance at removing phosphate: 7/8/15 -29% removal
8/4/15 -60%

2016 Monitoring Report: Volume Flow estimate = 218.9 M gal / 7.48 gal/ft^3 = 29.3 X 10^6 ft^3
Length of flow through filter = 29.3 X 10^6 / 4200 = **6,976 ft = 2,126 m**
Total Length through filter = 2,498 m + 2,126 m = **4,624 m (15,171 ft)**
Performance at removing phosphate: 5/3/16 -26% removal
6/23/16 0%

Conclusion: The MCWD IESF removed less than 50% of the inflow phosphate in 2013 and 2014, except for the event on 7/23/2014 in which 72% of phosphate was removed. After 2014, the removal was less than zero, indicating that phosphate was released from the filter and increased the phosphate concentration from inflow to outflow. This occurred after approximately 1,578 meters (5,163 ft) of flow estimated through the filter before removal ceased. However, the removal of phosphate from the water flowing through the IESF was below 50% during the first year of monitoring (2013). We must therefore estimate the life expectancy for performance greater than 50% removal at less than 2,050 ft of water.

IESF #2: Capitol Region Watershed District Williams Street IESF pond-perimeter trench

Installed in 2012: Two pond-perimeter IESFs. Phosphate concentration was measured at each, but flow measurement was combined. The results of the flow and phosphate removal are shown in Table 1.

North bench: L = 38’	W = 3 ft	Surface area = 114 ft^2
South bench: L = 123’	W = 3.7 ft	Surface area = 455 ft^2
		Total surface Area = 569 ft^2

Table 1: Median annual phosphate removal for Williams Street IESF:

Year	Annual Filter flow	Filter Flow /Surface Area	Sum Filter Flow	Sum Filter Flow/SA	Median Phosphate Removal
	CF/Yr	ft	CF	ft	%
2013	1,144,714	2,012	1,144,714	2,012	84.2
2014	1,144,714	2,012	2,289,429	4,024	79.7
2015	870,000	1,529	3,159,429	5,553	72.1
2016	817,000	1,436	3,976,429	6,988	48.8
2017	1,096,000	1,926	5,072,429	8,915	49.4
2018	1,495,000	2,627	6,567,429	11,542	68.8
2019	569,000	1,000	7,136,429	12,542	61.8
2020	1,405,000	2,469	8,541,429	15,011	5.8
2021	1,761,000	3,095	10,302,429	18,106	11.9
Ave	1,144,714				

Conclusion: The Williams Street IESF had a phosphate removal removal that seemed to drop substantially in 2020. This corresponds to 12,524 ft of flow estimated through the filter before the substantial reduction in phosphate removal. The 12,524 ft is substantially greater than seen in the Dutch Lake IESF, where phosphate removal was reduced to below 50% after less than 2050 ft of flow through the filter. One possible reason in the slow flow through the filter of 0.01 to 0.02 in/hr, caused by the filter fabric and allowing more contact time for water with the iron.

The cross-section view of the north and south IESFs at William Street Pond are provided in Figure 1.

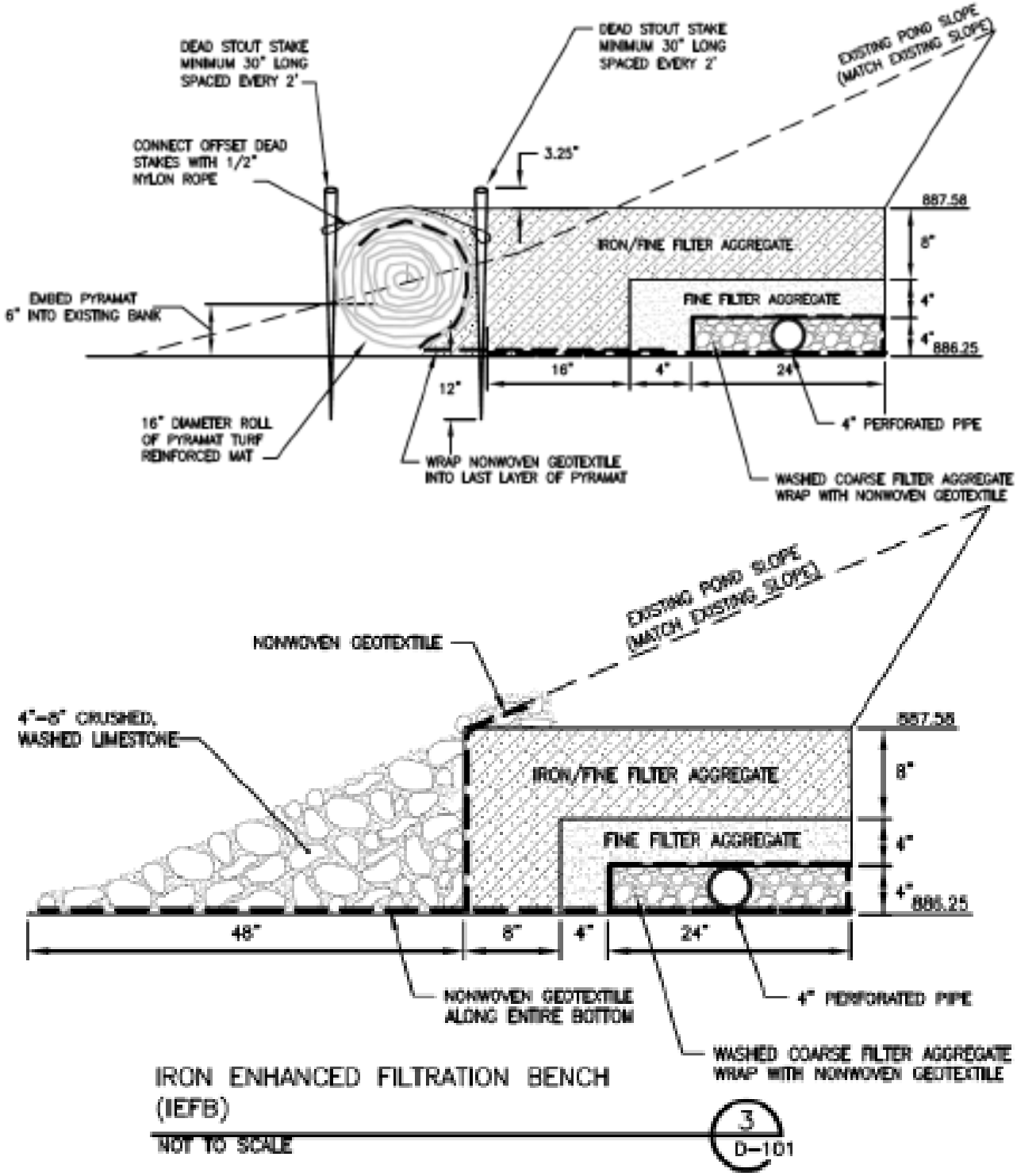

Figure 1. Section view of Williams Street IESFs: South (top) and North (bottom)

IESF #3: Martha Lake IESF filtration basin

From 2012 – 2014, ~290 m (~950 ft) of water was treated by the filter. Treatment effectiveness is unknown. The results of the 2015 (Table 2) and 2016 (Table 3) treatment years are given below, indicating that the IESF was reducing phosphate by roughly 2/3. The sampling dates were not all-inclusive for the year, however, so we will use the method used in Erickson, et al. (2017) to determine total volume and length of flow treated by the filter.

From 2012 – 2016, there were 950 ft + 86.6 ft + 121.5 ft = 1,158 ft of water passed through the filter (Erickson, et al. 2017). The data taken by the Wright Soil and Water Conservation District is given below (Table 4). Phosphate removal appeared to be below 50% in the early portions of 2017, with exceptions on 5/18/17 and 6/28/17. We will therefore designate 1200 ft as the cutoff time for good performance by the Martha Lake IESF.

Table 2: 2015 phosphate removal performance for the Martha Lake IESF

				Phosphate				
Rainfall Start	**Rainfall depth [in]**	**Flow Volume IN [ft^3]**	**Percent Exceedance by Filtered Volume**	**EMC IN [μg/L]**	**EMC OUT [μg/L]**	**Load IN [g]**	**Load OUT [g]**	**Load Removal [%]**
7/6/15	1.54	4,803	47%	68.0	13.9	9.2	1.9	**80%**
7/16/15	1.9	17,019	3%	238.3	42.0	114.8	20.2	**82%**
7/24/15	0.78	2,801	75%	54.1	8.1	4.3	0.6	**85%**
7/28/15	0.73	3,601	66%	55.6	11.8	5.7	1.2	**79%**
10/8/15	0.7	1,000	100%	100.2	15.1	2.8	0.4	**85%**
10/23/15	1.29	3,715	63%	68.4	16.7	7.2	1.8	**76%**
10/27/15	1.46	11,408	16%	211.8	96.5	68.4	31.2	**54%**
10/30/15	0.39	10,204	22%	201.9	88.8	58.3	25.7	**56%**
11/2/15	N/D	5,601	41%	145.1	55.6	23.0	8.8	**62%**
11/6/15	N/D	2,000	88%	102.3	53.4	5.8	3.0	**48%**
11/11/15	0.81	3,801	56%	122.7	52.7	13.2	5.7	**57%**
11/13/15	0.4	3,801	59%	112.0	65.4	12.1	7.0	**42%**
11/16/15	1.79	16,812	6%	132.2	63.2	62.9	30.1	**52%**
2015 Arithmetic Average =	**1.07**	**6,659**				**29.8**	**10.6**	
2015 Flow-Weighted Average =				**158.2**	**56.1**			
2015 Totals =	**11.8**	**86,567**				**387.9**	**137.6**	
2015 Load Removal Efficiency ± 95% Confidence Interval								**64.5% ± 9.4%**

Table 3: 2016 phosphate removal performance for the Martha Lake IESF

				Phosphate					Total Phosphorus				
Rainfall Start	**Rainfall depth [in]**	**Flow Volume IN [ft^3]**	**Percent Exceed-ance**	**EMC IN [μg/L]**	**EMC OUT [μg/L]**	**Load IN [g]**	**Load OUT [g]**	**Load Removal [%]**	**EMC IN [μg/L]**	**EMC OUT [μg/L]**	**Load IN [g]**	**Load OUT [g]**	**Load Removal [%]**
5/23/16	1.93	13,611	9%	20.8	17.3	8.0	6.7	**17%**	168.7	62.7	65.0	24.2	**63%**
5/27/16	0.3	6,802	31%	18.3	16.6	3.5	3.2	**9%**	213.5	109.8	41.1	21.1	**49%**
6/3/16	0.36	2,200	84%	89.1	13.8	5.6	0.9	**85%**	752.4	60.0	46.9	3.7	**92%**
6/12/16	0.74	1,400	97%	95.3	17.0	3.8	0.7	**82%**	1,516.4	83.0	60.1	3.3	**95%**
6/17/16	0.16	2,400	78%	78.0	15.5	5.3	1.1	**80%**	186.9	63.4	12.7	4.3	**66%**
7/5/15	1.89	7,405	25%	N/D	N/D	N/D	N/D	N/D	241.3	73.8	50.6	15.5	**69%**
7/10/16	0.62	1,600	94%	80.4	16.1	3.6	0.7	**80%**	138.4	56.4	6.3	2.6	**59%**
8/10/16	2.88	7,209	28%	358.3	109.5	73.1	22.4	**69%**	488.0	184.8	99.6	37.7	**62%**
8/12/16	0.07	6,402	34%	291.8	100.0	52.9	18.1	**66%**	373.5	135.0	67.7	24.5	**64%**
8/19/2016a	1.03	3,004	72%	284.2	84.8	24.2	7.2	**70%**	575.7	148.2	49.0	12.6	**74%**
8/19/2016b	0.46	17,211	0%	322.2	126.6	157.0	61.7	**61%**	365.8	176.4	178.3	86.0	**52%**
8/23/16	0.05	2,200	81%	132.2	63.5	8.2	4.0	**52%**	324.1	117.6	20.2	7.3	**64%**
8/27/16	0.21	1,800	91%	96.0	12.0	4.9	0.6	**87%**	755.7	79.0	38.5	4.0	**90%**
8/29/16	1.87	10,615	19%	252.5	55.9	75.9	16.8	**78%**	421.2	97.9	126.6	29.4	**77%**
8/31/16	1.28	13,606	13%	180.2	84.0	69.4	32.4	**53%**	307.2	128.6	118.3	49.6	**58%**
9/6/16	0.03	6,203	38%	208.8	94.2	36.7	16.6	**55%**	376.3	142.0	66.1	24.9	**62%**
9/9/16	0.02	5,401	44%	151.5	39.0	23.2	6.0	**74%**	294.4	99.4	45.0	15.2	**66%**
9/15/16	0.33	4,401	53%	N/D	N/D	N/D	N/D	N/D	1,166.4	342.5	145.3	42.7	**71%**
10/16/16	0.34	3,401	69%	50.2	42.3	4.8	4.1	**16%**	183.3	106.2	17.6	10.2	**42%**
10/18/16	N/D	4,601	50%	62.0	35.0	8.1	4.6	**43%**	141.8	78.1	18.5	10.2	**45%**
2016 Arithmetic Average =	**0.77**	**6,074**				**31.6**	**11.5**				**63.7**	**21.5**	
2016 Flow-weighted Average =				**165.2**	**60.3**				**370.3**	**124.7**			
2016 Totals =	**14.6**	**121,474**				**568.2**	**207.5**				**1,273.6**	**429.0**	
2016 Load Removal Efficiency ± 95% Confidence Interval								**63.5% ± 12.2%**					**66.3% ± 6.7%**

Table 4: 2017 – 2022 Phosphate removal for the Martha Lake IESF.

Event Date	Event Volume	PO4 Influent	PO4 Effluent	PO4 Removal	Fe Influent	Fe effluent	TP Effluent	TP Removal
	ft^3	mg/L	mg/L	%	mg/L	mg/L	mg/L	%
2/22/17		0.115	0.062	46	1.1	0.36	0.166	50
3/20/17		0.074	0.038	49	1.2	0.32	0.067	78
5/1/17		0.068	0.139	-104	0.08	0.44	0.224	-215
5/18/17	3499	0.286	0.111	61	1.4	0.63	0.144	66
6/1/17	1375	0.044	0.032	27	0.28	25.2	0.497	-418
6/15/17	2772	0.054	0.059	-9	1	4.1	0.307	-30
6/28/17	10621	0.138	0.051	63	5.7	0.3	0.073	94
7/12/17		0.013	0.053	-308	6.3	2.2	1.67	-428
10/5/17		0.196	0.128	35			0.152	47
10/19/17		0.056	0.102	-82			0.406	-69
10/19/17		0.056	0.102	-82			0.406	-69
11/9/17		0.05	0.089	-78	1	6.2	0.161	24
4/23/18		0.135	0.098	27			0.192	24
5/10/18		0.027	0.08	-196	1.36	2.13	0.208	47
6/6/18		0.037	0.083	-124	3	2.2	0.301	25
6/19/18	41,132	0.044	0.091	-107	2.88	0.197	0.09	85
7/5/18		0.062	0.091	-47	1.17	1.19	0.271	5
9/6/18		0.159	0.126	21	0.347	8.38	0.594	-330
9/20/18		0.12	0.09	25	2.43	1.33	0.158	71
10/11/18		1.21	0.385	68			0.424	68
5/30/19		0.112	0.237	-112	0.725	2.11	0.253	0
6/13/19	9928	0.062	0.165	-166	2.06	3.12	0.464	-19
6/26/19	2330	0.09	0.165	-83	0.536	0.578	0.215	-26
7/10/19	6870	0.052	0.159	-206	0.979	5.44	0.538	-148
7/25/19	41,757	0.068	0.165	-143	1.2	9.67	0.737	-235
8/20/19	6531	0.792	0.285	64	1.61	0.31	0.311	66
10/2/19	NA	0.439	0.326	26			0.356	31
5/13/20		0.021	0.126	-500	1.22	3.69	0.378	47
5/26/20		0.044	0.154	-250	1.28	0.879	0.247	5
6/9/20		0.066	0.175	-165	5.98	4.82	0.501	76
6/22/20		0.06	0.155	-158	0.57	67.8	1.77	-1251
7/7/20		0.067	0.144	-115	0.555	0.164	0.156	21
7/21/20		0.195	0.139	29			0.295	72
8/4/20		0.103	0.179	-74	0.579	18.2	1.4	-567
8/18/20		0.203	0.231	-14	1.56	6.6	10.5	-3223
9/1/20		0.082	0.162	-98	0.498	4.48	0.177	39
9/16/20		0.072	0.166	-131	2.46	0.676	0.194	87
10/13/20		0.084	0.137	-63	0.501	0.511	0.148	0
3/9/21		1.22	0.787	35	0.31	0.07	0.762	37
3/17/21		0.077	0.175	-127	2.27	0.1	0.165	4
4/6/21		0.095	0.156	-64	0.47	0.15	0.164	-4
4/27/21		0.093	0.162	-74	0.63	0.07	0.152	28
5/13/21		0.1	0.188	-88	0.85	0.18	0.127	95
5/25/21		0.287	0.19	34	0.83	0.17	0.214	61
6/8/21		0.173	0.122	29	0.9	0.89	0.176	67
10/21/21		0.12	0.193	-61	0.15	0.46	0.195	12
11/3/21		0.071	0.15	-111	<0.05	0.41	0.187	-105
3/22/22		0.17	0.25	-47	0.21	0.23	0.296	-10
4/5/22		0.106	0.166	-57	0.24	>0.05	0.175	6

The most consistent result of the measurements was phosphate effluent concentration, given in Figure 2 below. This indicates that average phosphate effluent concentration crossed 0.06 mg/L at the start of the 2017 field year. This corresponds to phosphate reduction by the IESF crossing below 50%.

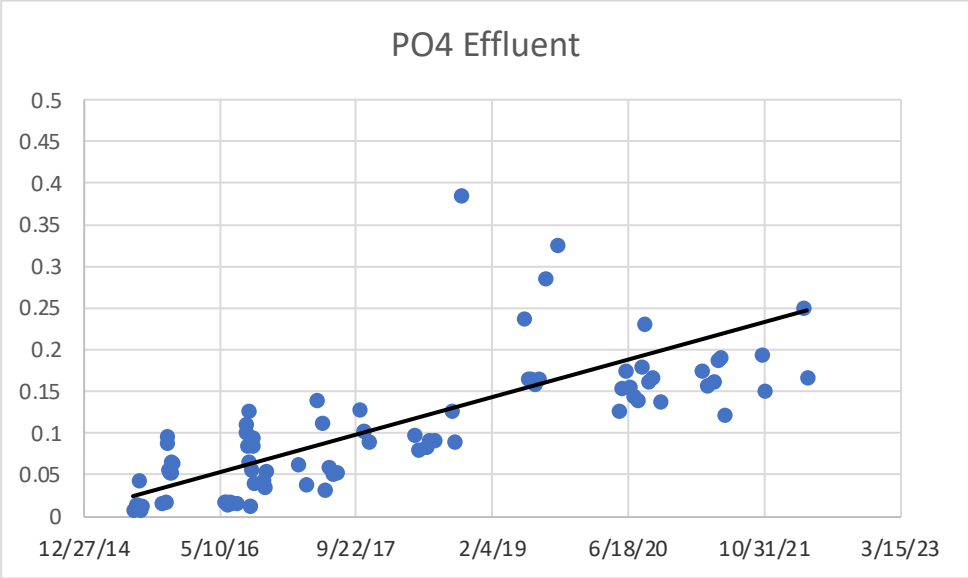

Figure 2: Phosphate Effluent for the Martha Lake IESF from 2017 - 2022

Conclusion

The three IESF practices have different amounts of water passing through before they cease to be a phosphate reduction practice. The values were approximately 12,500 ft for the Williams Street pond-perimeter trench, less than 2,050 for the Dutch Lake pond-perimeter trench, and 1,200 ft for the Martha Lake basin. The rationale for these differences is as follows:

- The Williams Street pond-perimeter trench had a slow-flowing filter fabric at the downstream end of the IESF, which restricted drop in the pond to 0.2 to 0.5 in/day. This would allow the water to have access to the oxidized iron below the saturated surface layer, and provide a longer treatment life.
- The Dutch Lake pond-perimeter trench was the most representative of the practices in Minnesota, treating most of the water that ran through the pond. However, the percent removal of phosphate by the IESF was below 50 % through most of the measurements, and the life of the IESF's removal capability at greater than 50% is estimated at less than 2050 ft of water.
- The Martha Lake basin water distribution management system (distributing water over the entire basin) failed due to a high solids load from the watershed. It was active only for a short time, and was removed. There are likely portions of the IESF that will still remove phosphate, and water should be channeled to those areas. We believe, however,

that the Martha Lake basin is the best representative of the length of phosphate removal above 50% from the water, at ~1,200 ft of water.

We believe that 1,200 ft of water is the most realistic IESF lifetime guideline to receive full pollution reduction credit for the State of Minnesota.

References

Erickson, A.J., J.S. Gulliver, P.T. Weiss. (2017). Monitoring an Iron-Enhanced Sand Filter for Phosphorus Capture from Agricultural Tile Drainage. SAFL Project Report No. 581, University of Minnesota, Minneapolis, MN. June 2017. http://hdl.handle.net/11299/188974